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COMMON EPIDERMAL LESIONS OF THE BOWHEAD WHALE, *BALAENA MYSTICETUS*

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Abstract

Samples of common skin abnormalities from 23 subsistence-harvested bowhead whales (*Balaena mysticetus*) were examined. Most lesions fell into three broad classes: shallow lacerations, circular depressions, and epidermal sloughing. Both circular depression lesions and epidermal sloughing lesions may be divided into more than one subgroup based on morphological criteria. Examination of each of the subgroups using light and scanning electron microscopy suggests relationships among the subgroups of a class. These proposed relationships are discussed, as are some possible etiologies. Scanning electron microscopy reveals abundant bacteria and diatoms present in association with each lesion class but no evidence of a particular association characteristic of a lesion class. The microflora were especially abundant wherever the stratum spinosum was exposed at the skin surface.

Key words: Skin lesion, whale, cetacean, epidermis, *Balaena mysticetus*, integument.

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Introduction

The bowhead whale, *Balaena mysticetus*, is a large (20 m), Arctic baleen whale that was brought near extinction by commercial whaling (Durham, 1972). Today, the Bering Sea bowhead whale stock has recovered to approximately 8,000 animals with a rate of increase of 3.1% (International Whaling Commission, 1995). Only subsistence hunts conducted by Eskimos of coastal Alaska are permitted. Because it is an endangered species and is a culturally and nutritionally important resource, efforts are being made to understand its biology. Some morphological investigations have been reported (for a review, see, Haldiman and Tarpley, 1993), but common departures from normal morphology should also be characterized. Such baseline morphological information may prove crucial in assessing the impact of human activity, particularly as petroleum development continues.

Skin abnormalities in cetaceans have been noted previously (Albert *et al.*, 1980; Cowan, 1966; Greenwood *et al.*, 1974; Haldiman *et al.*, 1981, 1982, 1983, 1985; Harrison and Thurley, 1974; Heckman *et al.*, 1987; Howard *et al.*, 1983; Ivashin and Golubovsky, 1978; Kenny and Everitt, 1980; Martineau *et al.*, 1988; Migaki, 1980; Sergent, 1962; Sylvester, 1980), but most investigations center on smaller odontocetes. Lesioned areas of bowhead whale skin are of additional concern because the roughened areas represent potential sites for the adherence of spilled petroleum (Albert, 1981) and because it is consumed by man. This investigation aims to describe lesions regularly found on the skin of a large mysticete.

As normal bowhead whale skin presents some unusual features, a brief description is presented here. The animal is covered with an extremely thick, smooth, grey-black, integument with white patches on the chin and occasionally the tail stock (Haldiman *et al.*, 1981, 1985). The epidermis (Fig. 1) is 10-22 mm thick over most of the body and may be up to 25 mm thick in places (Haldiman *et al.*, 1985, 1986). As in other cetaceans, it is parakeratotic and without a stratum

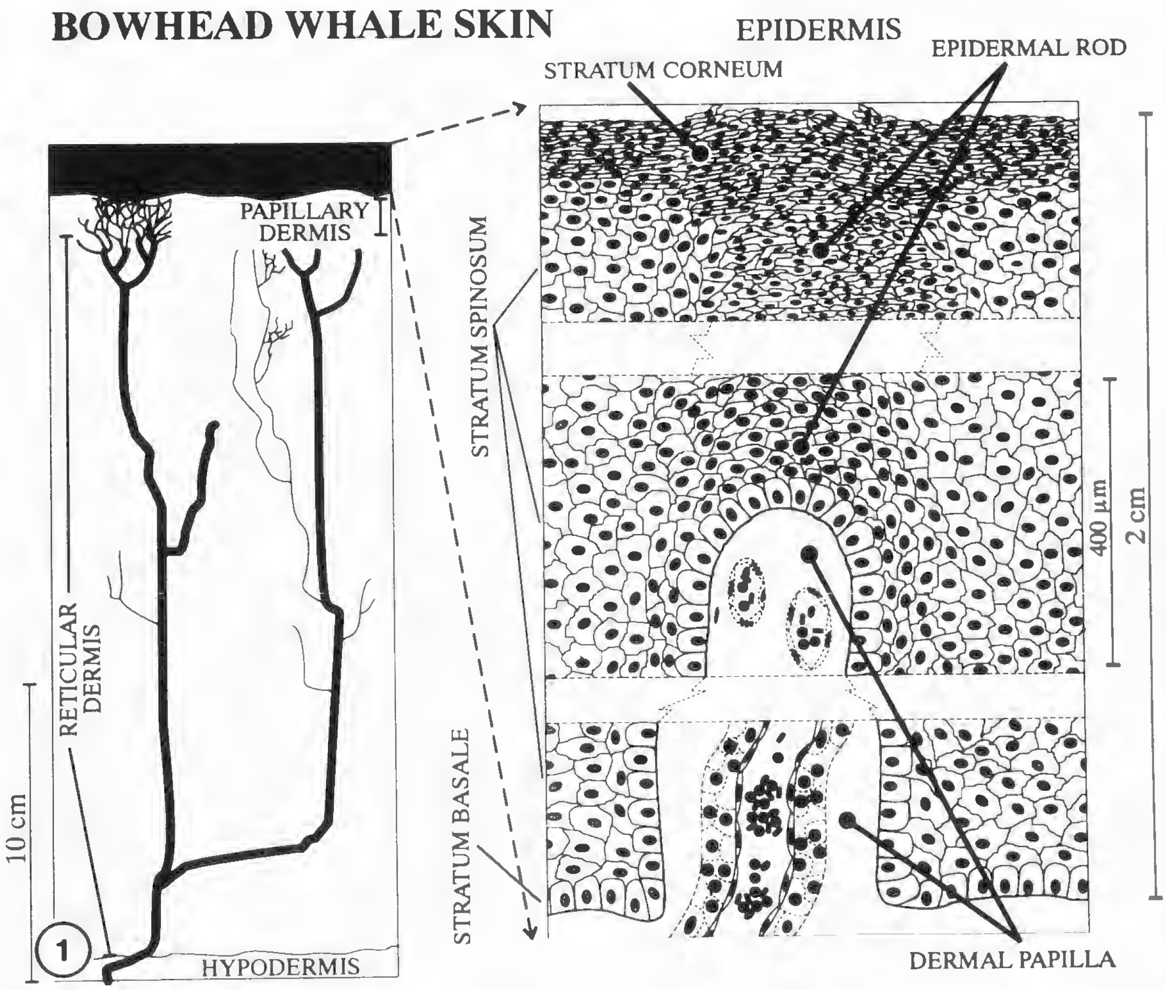

Figure 1. Diagrammatic representation of full thickness bowhead whale skin (left) and higher magnification of epidermis (right). Bars nearest figure represents magnification. Bar farthest right represents full epidermal thickness. Spaces between illustrated tissue (right) represent segments of the epidermis removed to accommodate scale.

granulosum. The underlying dermis (Fig. 1) is up to 300 mm thick (Fetter and Everitt, 1981).

Where the epidermis is thicker than 10 mm, epidermal rods (Fig. 1) are present (Haldiman *et al.*, 1981, 1985, 1986). The rods are solid cylinders of small tightly packed cells of the stratum spinosum that arise along the sides and tips of the dermal papillae. As with other cells, they become keratinized in the stratum corneum, but continue to remain well-defined, appearing as rosettes on the skin surface (Haldiman *et al.*, 1981, 1985, 1986).

Dermal papillae extend into the epidermis but never to more than about one half its total thickness. These dermal papillae arise from a thin papillary bed immediately beneath the epidermis (Fig. 1). Beneath the papillary dermis lies a thick fibrous reticular dermis infiltrated with adipocytes followed by a relatively thin hypodermis (Fig. 1) (Haldiman *et al.*, 1985).

Materials and Methods

Samples of lesioned and nearby normal skin were collected from 23 bowhead whales subsistence-harvested between 1979 and 1988. Note was made of the sex and body length of each animal and the samples shipped to Louisiana State University in 10% buffered formalin. Lesions were then segregated into morphologically similar groups, measured, and representative samples selected for detailed examination.

For histologic examination, specimens were dehydrated through isopropyl alcohol, and embedded in paraffin. Sections were stained using hematoxylin and eosin and Milligan's trichrome to reveal keratinization.

For scanning electron microscopy (SEM) specimens were washed free of aldehyde with 0.1 M sodium phosphate buffer, treated with tannic acid, and post-fixed with osmium tetroxide. Samples were then dehydrated

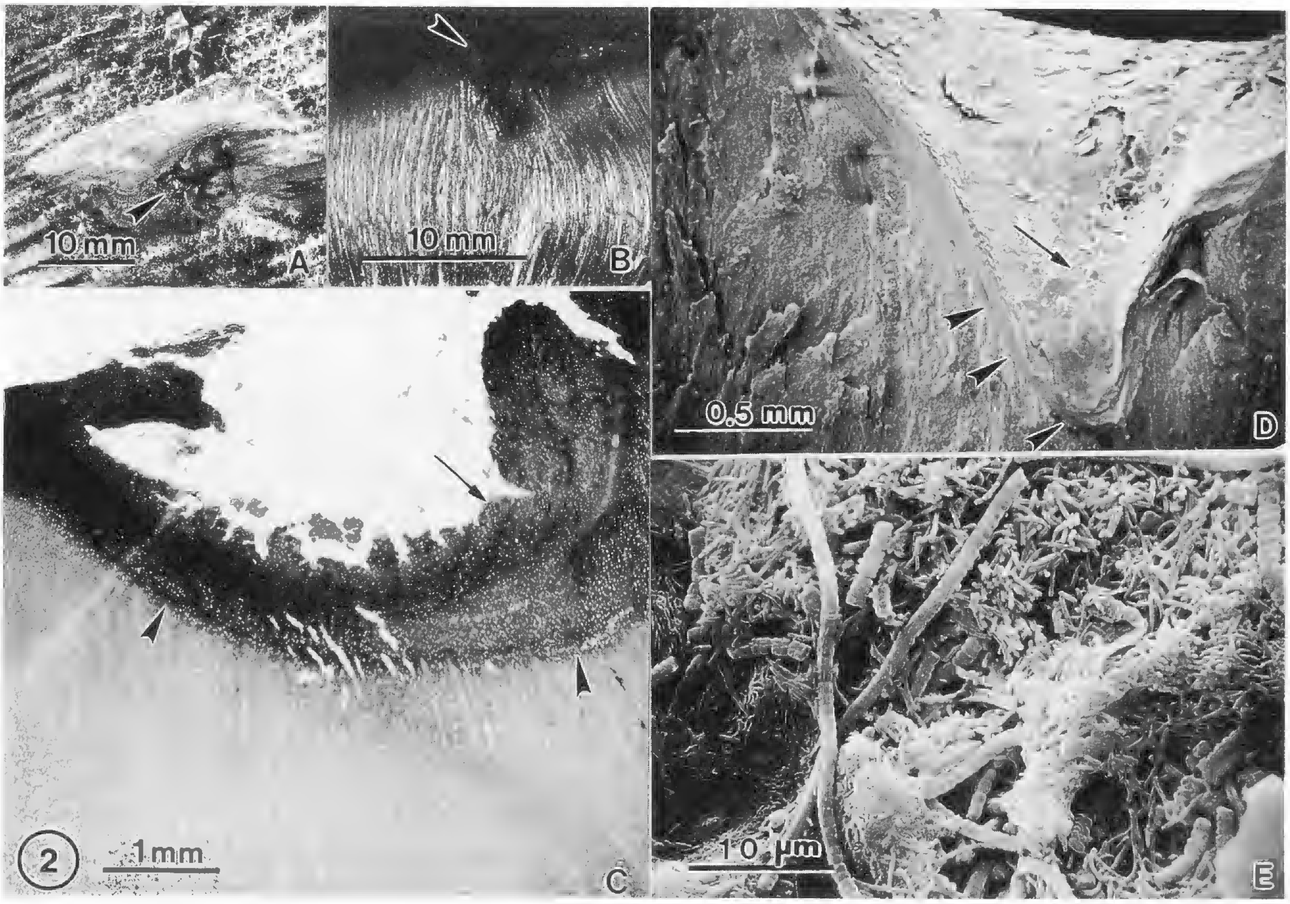

Figure 2. Superficial lacerations of bowhead whale skin. **(A)** Surface photograph of a typical laceration (arrowhead). **(B)** The same lesion sectioned perpendicular to skin surface. The lesion (arrowhead) extends approximately 5 mm into the epidermis but does not contact dermal papillae that terminate about 10 mm from the skin surface. **(C)** Photomicrograph of a section through a similar lesion stained using Milligan's trichrome procedure in which the keratinized stratum corneum is stained bright red (dark in these monochromatic images). Dark region of keratinization beneath the lesion is indicated by arrowheads. Accumulated spinosal cells are also evident above the keratinized layer (arrow). **(D)** Scanning electron micrograph of a superficial laceration sliced perpendicular to the skin surface. As in (C) accumulated spinosal cells (arrow) are seen above region of keratinization (arrowheads) that forms the lower boundary of the lesion. **(E)** Scanning electron micrograph of the surface of a portion of a superficial laceration lesion. Extensive microflora are associated with the damaged epidermis.

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in ethanol, critical point dried (Sweney and Shapiro, 1977), and sputter-coated with gold-palladium.

Results

Most lesions fell into three classes: shallow lacerations, circular depressions, and areas of epidermal sloughing. Each class occurred in both sexes. These lesions penetrated well into the epidermis but never reached the dermal papillae or produced evidence of dermal involvement.

Shallow Lacerations

These small, superficial, often linear lacerations were found on samples from 7 whales. Most are deeper at one end with some peripheral abrasion (Figs. 2A and 2B arrowheads). Their size (excluding abraded areas) ranged from 5 to 29 mm long by 3 to 7 mm wide and from 2 to 22 mm deep. The abraded area and laceration margins were slightly discolored.

Microscopic examination reveals that most wounds are lined by necrotic spinosal cells (Figs. 2C and 2D, arrows). A region of cornification beneath the laceration (Figs. 2C and 2D, arrowheads) blends into the stratum corneum of surrounding unaffected epidermis. In some lacerations the cornified region forms a complete layer that effectively isolates the damage. Where abraded areas surround the wound, the stratum corneum is missing or damaged and the exposed stratum spinosum appears necrotic (Figs. 2C and 2D arrows). Large numbers of microorganisms are found associated with debris and damaged spinosal tissue (Fig. 2E).

Circular depression lesions

These lesions were seen in samples from 15 whales. Each had a distinctly circular to oval outline and was depressed below the surrounding epidermal surface (Figs. 3A through 3D). Most were less than 10 mm in diameter and 5 mm deep (Figs. 3B and 3D), but a few were larger (up to 50 mm in diameter and 10 mm deep). They occur singly or in clusters and about half are distinguished by having slightly elevated rims (Figs. 3A, 3B, 3E and 3F arrowheads). Rimmed lesions are usually filled with necrotic spinosal cells and debris (Figs. 3B and E asterisk) while rimless lesions often appear as smooth-surfaced, hemispherical depressions (Fig. 3D). Rimless lesions are frequently surrounded by a lighter area from which part or all of the stratum corneum is missing (Figs. 3C and 3H arrows).

When examined in more detail both rimmed and rimless circular depressions have a keratinized layer within the stratum spinosum beneath the depression (Figs. 3E and 3G arrows). At the periphery, this cornified layer is continuous with the stratum corneum of surrounding normal skin, but may be quite thin or sometimes incomplete below the center of the defect. Raised rims appear to result from a thickening of the marginal stratum corneum (Fig. 3E large arrow). Epidermal rods at the lesion margins bend away from the depression (Figs. 3E and 3G arrowheads), but near the center, rods may extend straight into the lesion (Figs. 3G and 3I asterisk). Microorganisms, especially bacteria, are most numerous where this necrotic tissue is present (Fig. 3J).

Epidermal sloughing lesions

Epidermal sloughing lesions were seen in samples from 14 whales. A few lesions were observed in their entirety measuring 14 mm to 130 mm in diameter with a more or less circular outline, but the samples examined microscopically were from larger lesioned areas. All appear to involve the sloughing of substantial patches of epidermis, but can be separated into three morphologically distinct subclasses. In subclass 1, thick, discolored epidermal tissue is raised 1-12 mm above the surrounding normal surface (Figs. 4A and 4B). A distinct dark line, continuous with the surface of the surrounding normal epidermis, underlies this discolored area (Fig. 4B arrows). The epidermis beneath the raised tissue is about the same thickness as the surrounding normal epidermis. The discolored layer of spinosal cells (Figs. 4E and 4F asterisk) is not uniform in thickness, but thinner near the edges and thicker near the middle, while the underlying epidermis is thicker near the periphery and thinner near the center. A surface stratum corneum is absent but keratinized cells are evident in the midst of the stratum spinosum (Fig. 4E arrowheads). This keratinization may be limited to cells of the epidermal rods, may extend to some cells between the rods, or may form a complete cornified layer. At the margins of the lesion, the keratinized region blends into the stratum corneum of the surrounding normal epidermis. In extensively keratinized lesions, there is a clear division of the stratum spinosum into a primary spinosum distal to the cornified layer and a secondary spinosum proximal to it. Epidermal rods are often heavily keratinized distal to the cornified layer (Fig. 4E arrows). In some instances keratinized epidermal rods extend well into the necrotic primary spinosum. When a thicker,

Figure 3 (on the facing page). Circular depression lesions. **(A)** Surface view of a circular depression lesion with raised rim. **(B)** Same lesion bisected perpendicular to skin surface. The raised rim (arrowhead) and plug of necrotic spinosal cells (*) are evident. **(C)** Surface view of a circular depression lesion lacking a raised rim and plug of spinosal cells. Area of abrasion of the stratum corneum (arrow) surrounds this lesion. **(D)** Same lesion bisected perpendicular to the skin surface. Absence of a raised rim and spinosal cell plug are evident. **(E)** Histological section of the lesion depicted in Figures 3A and 3B stained using Milligan's trichrome procedure to reveal keratinization. Raised rim (large arrow) and plug of necrotic spinosal cells (*) are evident. Region of keratinization (small arrows) extends to delineate the lower border of the lesion. Portion of an epidermal rod near the periphery of the lesion bending away from the lesion's center seen in tangential section (arrowhead). **(F)** Scanning electron micrograph of a circular depression lesion with a raised rim. The elevated rim is clearly evident (arrowheads). **(G)** Histological section from the rimless lesion depicted in Figures 3C and 3D. Heavily keratinized layer forms the lower surface of the lesion (small arrows). Epidermal rods near the lesion periphery bend away from it (arrowhead) while those more centrally located extend straight into the cornified layer at base of lesion (*). Developing secondary stratum corneum is also evident (arrowheads). **(H)** Scanning electron micrograph of the lesion depicted in Figures 3C, 3D and 3G. Area of abraded stratum corneum is evident (arrow) as is the smooth sloping margin of the lesion. **(I)** Circular depression lesion with raised rim in which extension of epidermal rods (*) into necrotic spinosal cell plug is evident. **(J)** Scanning electron micrograph of the microflora typical of the spinosal cell plug of many circular depression lesions.

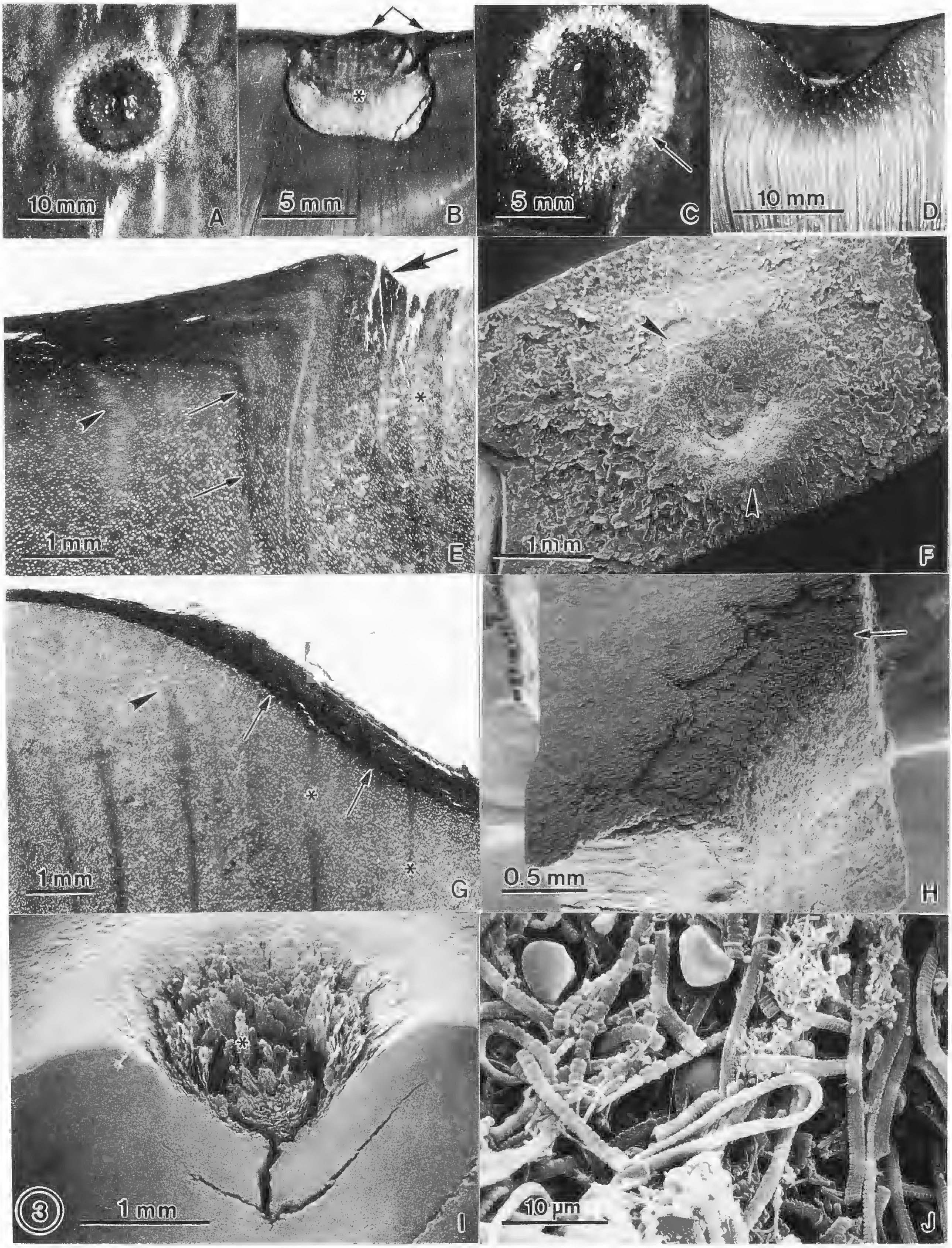
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Figure 4 (on the facing page). Epidermal sloughing lesions. **(A)** Surface view of portion of a typical raised (subclass I) sloughing lesion. Epidermal discoloration is evident. **(B)** View of lesion depicted in Figure 4A after it was sliced perpendicular to the skin surface. Raised discolored region is evident as is a dark band continuous with the surface that extends beneath the raised portion of the lesion. The light band extending down the center of the otherwise dark epidermis is the result of the glare produced because this relatively smooth exposed surface is curved. The epidermis always produces such a curved appearance when cut perpendicular to its surface. A similar, though less pronounced, effect is seen in Figures 4C and 4D as well. **(C)** Portion of second subclass of epidermal sloughing lesions sliced perpendicular to the skin surface. Protruding filaments are evident. **(D)** Photomicrograph of a portion of the third subclass of sloughing lesions. This subclass is characterized by a roughened undulating surface and slightly thinner stratum corneum that is otherwise typical. **(E)** Histological section through a part of lesion depicted in Figures 4A and 4B stained using Milligan's trichrome procedure. Raised portion of the lesion consisting of degenerating spinosal cells (*) is located on the left of this micrograph. Keratinized epidermal rods may be seen running through this layer (arrows). Beneath these degenerating spinosal cells is a region of incomplete keratinization (arrowheads) and to the right of that is a more normal appearing stratum spinosum. **(F)** Scanning electron micrograph of a slice of a subclass I lesion. Necrotic, spongy appearing spinosal cells (*) are evident. Vertical crack in the specimen runs through the area of incomplete keratinization seen in Figure 4E. **(G)** Histological section through part of lesion depicted in Figure 4C. Epidermal rods (arrows) form filaments that extend through and protrude above a thin necrotic spinosal layer. Region of keratinization (arrowheads) separates the necrotic portion of the stratum spinosum from an underlying unaffected spinosum. **(H)** Scanning electron micrograph of the lesion depicted in Figures 4C and 4D. Epidermal rods are evident (arrows). **(I)** A histological section through a subclass III lesion in which the surface irregularities and undulations are evident. **(J)** Scanning electron micrograph of a section through a subclass III lesion. Undulating stratum corneum is evident.

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more complete cornified layer is present, the interface between the secondary spinosum and the cornified layer is definite but the interface with the primary spinosum is less well defined. Microorganisms occur in large numbers in the necrotic primary stratum spinosum (Fig. 5A).

In the second subclass, patches of 1 mm diameter filaments project 1 to 5 mm above the surrounding epidermis (Figs. 4C, 4G and 4H). The epidermis itself is about the same color and thickness as surrounding normal epidermis. The protruding filaments are actually keratinized epidermal rods plus adherent spinous cells. They extend through the thick, undulating cornified layer and a thin, patchy primary spinosum to project above the surface (Figs. 4G and 4H arrows). Microorganisms are most abundant in patches of necrotic spinosum.

The third subclass is (Figs. 4D, 4I and 4J) characterized by a rougher more undulating surface than occurs in surrounding normal tissue. Histologically this surface is a stratum corneum similar in appearance to the secondary cornified layer but without a superficial necrotic spinosum or projecting keratinized filaments. Relatively few microorganisms were observed on the surface.

Microorganisms

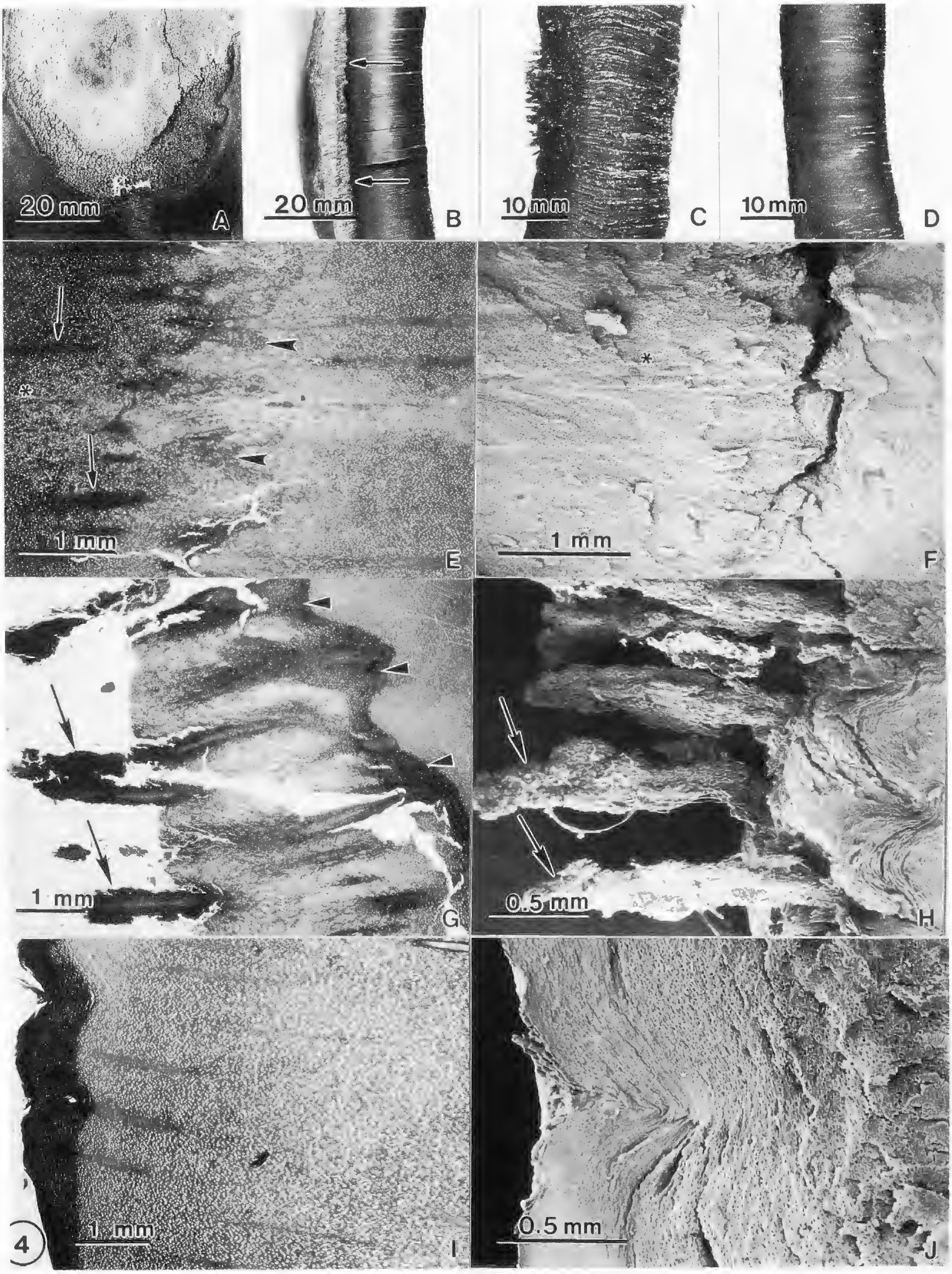
Several different microorganisms were seen on the epidermal surface. Of these, cocci, bacilli, and filamentous bacteria are the most common (Figs. 2E, 3J, 5A and 5B). Bacteria seem to occupy two general areas. When an intact stratum corneum is present, they accumulate in sheltered areas created by partially desquamated cells (Fig. 5B), while in damaged epithelium they occur in large numbers wherever spinous cells are exposed to the environment without the protection of a keratinized layer (Figs. 2E, 3J and 5A). The more necrotic the tissue appears, the larger the bacterial numbers. Bacteria infiltrate quite deeply into an exposed spinous layer, penetrating between cells and filling empty spaces once occupied by cells. Penetration through a continuous keratinized layer, whether it appears at the surface or within the stratum spinosum was not observed.

Diatoms were also seen on the epidermis (Fig. 5B). The large, oval *Cocconeis sp.* occurs in low numbers and seems to remain at the epidermal surface while longer, narrower *Stauroneis* and/or *Navicula* species infiltrate exposed spinous layers along with bacteria, but do not penetrate as deeply. As with bacteria, diatoms are more numerous on disrupted epidermal surfaces.

Protozoa and fungi were occasionally observed in histological sections. As with other microorganisms, they were more numerous on disturbed epidermal surfaces.

Discussion

This study of bowhead whale skin lesions included samples from 23 whales of both sexes. Most skin lesions fell into one of three classes: superficial lacerations, circular depression lesions, and epidermal sloughing lesions, none of which penetrate to the dermal papillae. Each of the three classes described here occurs in both sexes, but since the number of animals was small, and the distribution of animals among the two sexes was not equal, little else can be said.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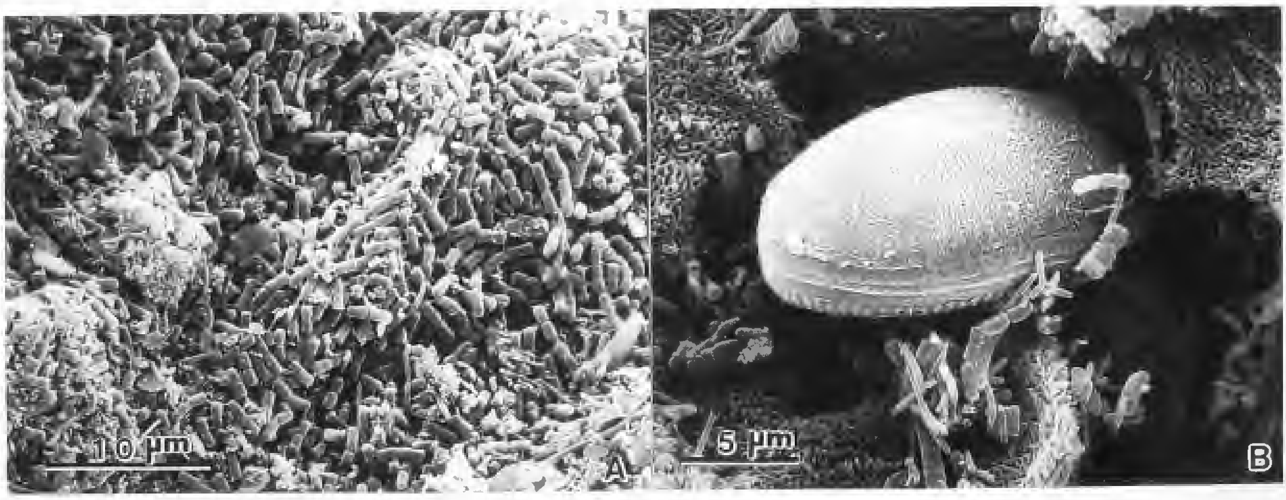

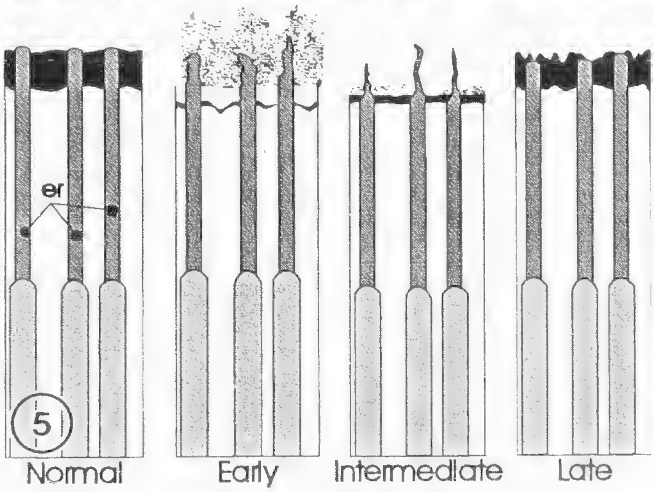

Figure 5. Epidermal sloughing lesions. **(A)** Extensive microflora typical of regions where necrotic spinosal cells are exposed (subclasses I and II). **(B)** Reduced microflora where an intact stratum corneum is present. **(C)** Diagrammatic representation of a proposed progression of changes in the epidermal surface that account for all three subclasses seen in epidermal sloughing lesions. Early lesions (subclass I) represent the loss of the original stratum corneum leaving behind a stratum spinosum that becomes necrotic. Second cornified layer develops at some distance beneath the degenerating stratum spinosum. Intermediate lesions (subclass II) involve a better developed secondary stratum corneum and a continuing disintegration of the old stratum spinosum. The heavily cornified epidermal rods (er) remain for some time as the stratum spinosum disappears. Late lesions (subclass III) are characterized by a complete but rough and undulating stratum corneum, but the entire old stratum spinosum including the epidermal rods has disappeared. In time, the surface may lose its undulations and become indistinguishable from the surrounding skin.

Superficial lacerations

Various wounds have previously been described in cetaceans and possible causes suggested. Greenwood *et al.* (1974) provide an extensive review of this topic, and suggest three general etiologies for wounds and scars: circular scars resulting from ectoparasites, parallel scratches from odontocete teeth, and single marks or scars from sharp underwater objects. In bowhead whales, wounds from attacks by killer whales (*Orcinus orca*) have already been reported (George *et al.*, 1990; Mitchell and Reeves, 1980; Philo and George, 1990; Reeves and Leatherwood, 1985). These sources appear unlikely to account for the shallow non-scarring lacerations reported here which appear more likely to result from minor encounters with objects such as ice.

Since a partial or complete cornified layer, continuous with the stratum corneum of surrounding normal epidermis, underlies these lacerations, repair appears to be underway. The absence of dermal scarring or inflammation supports the view that these wounds are not partially healed remnants of deeper wounds.

Circular depression lesions

Three types of skin lesion reported by Haldiman *et al.* (1981): shallow depressions, granular deep depressions, and smooth deep depressions clearly fit within this class. Morphologies reported here (e.g., rimmed, rimless, filled, empty) suggest stages in the resolution of an injury rather than lesions with separate etiologies. An initial response would circumscribe the injury with a cornified layer. On the surface, that consists of a thickened stratum corneum producing a circumferential raised rim. A deeper cornified layer within the stratum granulosum and connected to the stratum corneum near the rim then effectively isolates the damaged granulosum. Next, movement of the newly keratinized layer toward the surface plus the disintegration and removal of the necrotic plug of granulosum would account for the morphologies observed. Rimless lesions with a surrounding exposed granulosum could simply reflect the mechanical removal of the rim and plug by hydrodynamic forces or contact with solid objects. The occurrence of more than one morphology in larger lesioned areas also argues against a separate etiology for each type of circular depression.

Causal agents for circular lesions have been identified in other cetaceans. Martineau *et al.* (1988), for example, describe circular depression lesions with raised rims resulting from a herpes virus infection in a beluga whale (*Delphinapterus leucas*), and Ivashin and Golubovsky (1978) describe circular wounds in a Bryde's whale (*Balaenoptera edeni*) from a copepod ectoparasite. Another possibility is suggested by the report of Shotts *et al.*, (1990) and Davis (1988) that some bacteria isolated from bowhead whale skin lesions have potentially erosive enzyme activity.

Epidermal sloughing lesions

Here, different morphologies more clearly represent stages in a single process (Fig. 5C). First, keratinization of the epidermal rods occurs at, and distal to, a developing layer of keratinization in the stratum spinosum. Eventually a continuous cornified layer develops within the stratum spinosum (subclass 1). Distal to the secondary stratum corneum the spinosum degenerates. The second, filamentous, stage is intermediate and may not always occur. Here most of the necrotic primary stratum spinosum is eroded away, leaving the tips of the keratinized epidermal rods extending above the continuous secondary stratum corneum (subclass 2). The number of keratinized rods and the extent of their keratinization influence the appearance of this stage. In lesions of the third subclass, the keratinized epidermal rods have been removed along with the remaining primary stratum spinosum, leaving the thick undulating secondary stratum corneum exposed at the surface. This new stratum corneum probably becomes smooth through desquamation to ultimately leave no trace of the lesion. This hypothetical sequence of events cannot be tested, but the presence of transitional stages, sometimes within a single lesion, makes it appear plausible. Additionally, a form of ecdysis where epidermal layers are lost in patches, or large sheets is thought to occur normally in some cetaceans (Durham, 1980; Harrison and Thurley, 1974; Ling, 1974; Spearman, 1972; St. Aubin *et al.*, 1990). The lesions might then represent stages in normal ecdysis. The fourteen animals from which these samples were taken ranged from 7.5-17.7 m ($\bar{x}$ 10.2 $\pm$ 1.8). It would thus appear that, if these lesions represent stages in ecdysis, the process is not confined to young animals. Alternatively, a loss of the stratum corneum as a result of some mechanical or microbial insult might produce a secondary keratinization in the stratum spinosum and a similar sequence of events. Several of the lesions previously identified by Haldiman *et al.* (1981) clearly fit into this class.

Microorganisms

Substantial numbers of bacteria and diatoms occur on the surface of healthy bowhead whale skin but greater numbers occur in areas of damaged epidermis (Haldiman *et al.*, 1981, 1985; Heckmann, 1981; Heckmann *et al.*, 1987). Davis (1984) and Shotts *et al.* (1990) cultured bacteria and yeasts from normal and lesioned bowhead whale skin and found that several species occur preferentially or exclusively on lesioned skin. In cetaceans, superficial bacterial infections are generally secondary to a disruption of the skin (Greenwood *et al.*, 1974 and Howard *et al.*, 1983), but Shotts *et al.* (1990) and Davis (1988) identified several erosive enzymes in the bacteria and yeasts from bowhead whale skin and suggested they might be pathogenic. In addition, some species isolated by Shotts *et al.*, are known pathogens of other mammals. Thus, it does not seem unreasonable that some of the epidermal lesions described here might result from the activities of these bacteria. Diatoms and protozoa, on the other hand, represent less likely causative agents. Even when diatom numbers are great enough to produce surface films visible to the naked eye they are not thought to result in pathology (Haldiman and Tarpley, 1993). Protozoa occurred only in small numbers.

Conclusions

The three common classes of lesions seen here on the skin of the bowhead whale are confined to the superficial epidermis and result in no inflammatory or other dermal response. Whatever the etiological agent or morphological form of the lesion, the general response to exposing the stratum spinosum, appears to be production of a secondary cornified layer of cells proximal to the affected area. This keratinized layer is continuous with the stratum corneum of unaffected skin at the edges of the lesion thus effectively circumscribing the damaged spinosum. Ultimately the secondary keratinized layer moves to the surface, as a new stratum corneum, healing the lesion without scarring.

While it seems clear that the skin lesions described here do not penetrate the epidermis and probably heal without scarring, an exposed stratum corneum offers increased micro-relief on an otherwise smooth surface. Such relief continues to suggest the potential for increased adherence of spilled petroleum (Albert, 1981).

Acknowledgments

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Discussion with Reviewers

B. Forslind: Can you make a comparison between the enormously thick epidermis of these whales and the furry integument of other water living mammals such as seals, or with pachyderms such as hippopotamus?
Authors: In general, water living animals including seals, hippopotami, sirineans and many cetaceans have a comparatively thin epidermis that ranges from less than 0.5 mm to 1.5 mm thick. The thickness of bowhead whale epidermis exceeds the total skin thickness most water living species except the sirineans and some larger cetaceans. In fact, bowhead whale epidermis is about 10 times thicker than the entire skin thickness of *Hippopotamus amphibius* (Wright, 1964) or *Pagophilus groenlandicus* (the harp seal; Tarasoff, 1974).

B. Forslind: You do not actually comment on the possible function of the epidermal rods. How do these compare to the proliferative unit of terrestrial mammal epidermis (Potten, 1974)?
Authors: We did not specifically seek to identify the proliferative units described by Potten. The highly irregular topography at the dermal epidermal junction make their identification rather difficult. It would be tempting, however, to speculate that epidermal rods result from a modification to specific proliferative units.

B. Forslind: Is the keratinization of the cells confined to these rods synchronous with that of the surrounding

stratum spinosum?
Authors: Haldiman *et al.* (1981) observed that keratinization of the rods begins deeper in the epidermis (presumably earlier) than in the surrounding stratum spinosum.

B. Forslind: Have you any idea if the desmosome numbers per cell are the same in the rods as in the surrounding epidermis?
Authors: No, but that information would certainly be useful in any speculation on the function of these rods.

B. Forslind: Is the distance between these rods such that they could represent an internal reinforcement of the extremely thick cellular tissue?
Authors: We have not conducted a quantitative study of the distribution of epidermal rods so a precise answer is not possible, but based on our own histological observations and the photograph in Haldiman *et al.* (1981), the rods appear to be numerous enough to have such a function. An investigation of the arrangement of the rods in three dimensional space might also shed some light on their functional significance.

B. Forslind: Are they present all over the whale integument or are there zones lacking these features.
Authors: The only area we have found epidermal rods missing is in the integument of the eyelids.

B. Forslind: From a functional point of view, can you comment on the unusual phenomenon of formation of a stratum corneum under a lesion.
Authors: At this time we can only speculate about possible mechanisms that produce the secondary cornification. The idea of an alteration in ion gradients within the epidermis resulting in a secondary cornification is both attractive and testable using particle probe analysis. Obtaining adequately preserved samples, however, presents serious difficulties that result from environmental and logistical conditions during sample collection. Regardless of the mechanism(s) that underlies the process, secondary cornification appears to effectively limit damage to the epidermis and ultimately returns the surface to its normally smooth condition.

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